

Using a submarine to monitor the biological recovery of deep sediments in Lake Geneva (Switzerland)

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Using a submarine to monitor the biological recovery of deep sediments in Lake Geneva (Switzerland). - Since 1980, Lake Geneva has been recovering from eutrophication as indicated by the decrease of phosphorus concentrations. Oligochaete communities, sampled in 1996 from the submarine F.A.-Forel, were used to monitor the recovery of deep sediments (185 m - 300 m). Biomass of oligochaetes decreased with depth. Species indicative of oligotrophic conditions (mostly *Spirosperma velutinum* and *Stylodrilus heringianus*) were abundant between 185 m and 240 m, but scarce deeper. This indicates that the biological recovery of sediments proceeds smoothly shallower than 240 m, but is delayed by the persistence of low oxygen concentrations at greater depths.

Key-words: Biomonitoring - Eutrophication - Indicator species - Lake - Oligochaeta - Zoobenthos.

INTRODUCTION

In Lake Geneva (582 km², 89 km³), total phosphorus concentrations, averaged over the whole water column (0 - 309 m deep), increased from 12 mg m⁻³ in 1957 to a maximum of 89 mg in 1979, then they regularly decreased down to 41 mg in 1995 (BLANC et al. 1996). Accordingly, Lake Geneva which was oligotrophic before 1950, as were the other large lakes of Switzerland (FRICKER 1980), became meso-eutrophic around 1980, but reversed to a mesotrophic state after 1990. This improvement can be explained by the ban of phosphorus in detergents and its removal by sewage treatment plants (CONSEIL SCIENTIFIQUE 1996). In 1995 for instance, the sewage of about 1.3 million inhabitants was treated by 156 plants in the 7400 km² drainage basin of Lake Geneva (RAPIN 1996).

Phytoplankton did not respond clearly to the decrease of phosphorus: in some years the biomass decreased, in other years the primary production decreased (DRUART et al. 1996, PELLETIER 1996). A clear-cut downward trend was presumably obscured by inadequate sampling (BLANC et al. 1993) and also by complex interactions between climate, phytoplankton, zooplankton, and fish (CRETENAY et al. 1996).

In contrast, zoobenthos responded clearly to the decrease of phosphorus, to at least 40 m deep. Mean relative abundance of species indicative of oligotrophic

conditions increased in oligochaete communities from 17% in 1982 to 41% in 1991 (LANG & REYMOND 1992). According to these values, Lake Geneva was meso-eutrophic in 1982, but mesotrophic in 1991 (LANG 1990). Deeper (150 m), the trend towards recovery was less clear, at least in 1993 (LANG & REYMOND 1995).

In this study, the depth-related recovery of deep sediments (185 m - 300 m) was monitored in 1996, using the composition of oligochaete communities as an indicator (LANG & REYMOND 1996a). The deepest area of Lake Geneva was selected because it will be the last to recover (LANG 1991), i.e. to be recolonized by the oligotrophic worm species which prevailed before the onset of eutrophication (JUGET 1967). This recolonization can be delayed by the persistence of low oxygen concentrations. Indeed, oxygen decreased between 1985 and 1996 because its stock in the deep layers (200 m - 309 m) has never been replenished since the cold winter of 1985 (BLANC et al. 1996).

STATIONS AND METHODS

SAMPLING SITES

In 1996, a 1200 m long transect was selected on the northern shore of Lake Geneva, in front of the city of Lausanne. It extends north-south and its depth varies from 185 m to 300 m. Its extreme coordinates, based on the national map of Switzerland, are 537.250 / 149.100 and 537.250 / 148.000 respectively. Due to its location, (LANG 1991), this area is adequate to assess the biological recovery of sediment because it receives mainly organic sedimentation derived from phytoplankton (LANG & REYMOND 1996a).

In September (18, 19, 24), three dives were made on this transect with the manned submarine F.A.-Forel to collect 24 sediment cores (50 cm long, 26.4 cm² each). The relatively small sample size results from financial (no more than 3 dives) and technical constraints (no more than 8 cores collected per dive). Depth range was selected according to the oxygen concentrations which decreased in 1995 from 8 mg l⁻¹ at 150 m to less than 3 mg l⁻¹ at 300 m (BLANC et al. 1996). Within this gradient, 24 depths were sampled, every 5 m: the first at 185 m, the last at 300 m. One sediment core was taken at each depth.

In this study, cores were collected from a submarine, not by a corer sent blindly from the surface. The first method is more expensive to use than the second, but it is more precise. So it was always possible to sample the same sedimentary structures, i.e. the pillows (see below). One source of variability affecting the composition of oligochaete communities (LANG 1989) was removed, facilitating the comparison between depths. In addition, the quality of cores collected by a submarine was high because, as for SCUBA diving (LANG 1989), it was possible to control visually the sampling. As more information was extracted from less cores, the cost of doing a survey with a submarine was justified by the quality of results.

In the studied sites, as over large areas of Lake Geneva (VERNET 1966), the sediment consists of pillow-like structures (0.7 m wide) separated by trenches (0.2 m wide by 0.1 m deep). Their origin is unknown.

Composition of zoobenthic communities is not the same for both structures (LANG 1989) because sedimentation rates are higher on pillows than in trenches (LOIZEAU et al. 1988). In this study, pillows were sampled rather than trenches because recent sedimentation was less disrupted on the former than in the latter (STURM et al. 1984). And restoration of sediment is directly linked to the quality and quantity of recent sedimentation.

SAMPLE PROCESSING

Sediment was sieved (mesh size 0.2 mm) and the retained material preserved in 5% formalin. The collected macrofauna consisted mainly of tubificid and lumbriculid worms which were picked and counted under a low magnification (3x) binocular microscope against a white background. They were weighed after removing excess water with blotting paper. Worms with a diameter equal or greater than 0.3 mm were mounted (REYMOND 1994) and identified up to species. Juvenile worms (diameter less than 0.3 mm) were excluded to decrease the effect of seasonal variability on species abundance (LANG 1991). Species whose numerical dominance in tubificid and lumbriculid communities indicates, respectively, oligotrophic, mesotrophic or eutrophic conditions (LANG 1991) were designated oligotrophic, mesotrophic, and eutrophic species in Table 1.

Relative abundance of the oligotrophic species, calculated as a percentage of the total number of adult worms present in each core, is used to monitor the extent of recovery (LANG & REYMOND 1996a). Mean relative abundance of these species is

TABLE 1
Depth-related changes in oligochaete communities of Lake Geneva in 1996

Code	Species	Depth (m)		
		185 - 300 (n = 24) ^a	185 - 240 (n = 12)	245-300 (n = 12)
1	<i>Bythonomus lemani</i> Grube	2 ^b	2	0
2	<i>Spirosperma velutinus</i> (Grube)	8	7	1
3	<i>Stylodrilus heringianus</i> Claparède	12	10	2
4	<i>Spirosperma ferox</i> (Eisen)	1	1	0
5	<i>Potamothrix vejdoskyi</i> (Hrabe)	1	1	0
6	<i>Potamothrix moldaviensis</i> (Vejdovsky)	3	3	0
7	<i>Limnodrilus profundicola</i> (Verrill)	1	1	0
8	<i>Potamothrix hammoniensis</i> (Michaelson)	24 ^c	12	12
9	<i>Potamothrix heuscheri</i> (Bretscher)			
10	<i>Tubifex tubifex</i> (Müller)			
	Oligotrophic species 1 - 3	27.5 (31.9) ^d	47.5 (30.7)	7.6 (17.9) ^e
	Mesotrophic species 4 - 6	2.8 (6.7)	5.6 (8.8)	0
	Eutrophic species 7 - 10	69.7 (31.9)	46.9 (26.1)	92.4 (17.9)
	No. of identified oligochaetes	181	131	50

a) Number of 26.4 cm² cores.

b) Number of cores in which the species was present.

c) Species 8 - 10 pooled.

d) Mean (standard deviation) relative abundance (%) per core.

e) Difference between depths significant: Mann-Whitney test, P = 0.001

around 70% in oligotrophic lakes, 52% in oligo-mesotrophic lakes, 35% in mesotrophic lakes, 17% in meso-eutrophic lakes, and they are absent from the profundal of eutrophic lakes (LANG 1990).

The mean concentration of total phosphorus (TP) in the water column (0 - 100 m), computed for the five years preceding the sampling of worms (i.e. 1991 - 1995), was 33.2 mg m^{-3} (BLANC et al. 1996). This value was used to predict the mean relative abundance (%) of oligotrophic worm species (OS) and the mean biomass (g m^{-2}) of zoobenthos according to the following empirical relationships.

$$\text{Equation 1} \quad \text{OS} = 80.29 - 8.35 \text{ TP}^{0.5} \text{ (LANG 1990)}$$

$$\text{Equation 2} \quad \log_{10} \text{biomass} = 0.708 \log_{10} \text{TP} + 0.092 \text{ (HANSON \& PETERS 1984)}$$

The predicted abundance of OS (32.2%) and the predicted biomass of zoobenthos (14.7 g m^{-2}) were used as yardsticks to evaluate the progress of recovery. If predicted and observed values are close, it means that recovery proceeds at the same rate in the water and in the sediment (LANG & REYMOND 1996a). If the observed values are lower than the predicted ones, it means that the recovery of sediment is delayed by the persistence of anomalous conditions, probably low oxygen concentrations.

Oxygen concentrations were not measured on the bottom during the sampling of worms, but before and in the water column (185 m - 300 m), using an oxygen probe calibrated against Winkler titrations (Paul Blanc, pers. com., station d'hydrobiologie lacustre, INRA, Thonon, France). For each depth, a mean concentration was computed using the value of 4 surveys: 2 in August, 2 in September 1996.

All computations and graphics were made with the SPSS software for Windows (NORUSIS 1993). The sampling design used in this study (one core per depth) has been selected because it was well adapted for regression analysis. Raw data were used in figures 1 and 2 after several transformations (arc sinus, log, square-root, and rank) had been tried.

RESULTS

VISUAL OBSERVATION

In the studied transect, as over large areas of Lake Geneva (VERNET 1966), the sediment consists of pillow-like structures separated by trenches (see Stations and methods). In the trenches, the sediment was covered by a white layer of *Beggiatoa*, a sulfur bacteria, whose abundance increased with depth between 255 m and 300 m. In contrast, this white layer was not seen between 185 m and 250 m.

Mass development of *Beggiatoa* occurs at the surface of completely reduced sediments, where H_2S reaches the oxygen of the open water (JØRGENSEN 1977). Hence proliferation of this bacteria indicates the presence of anoxic sediments in which only tolerant zoobenthic species are able to survive (LANG & REYMOND 1996b). For instance, no molluscs were observed on the sediment below 260 m.

On the studied transect, the mean bottom slope was around 9.6% (extremes: 2 - 30%). This relative steepness is advantageous to the zoobenthos in two ways: (1) the recolonization of deep sediments, for instance by the cocoons of oligochaetes, is

facilitated; (2) organic matter flows deeper, therefore the zoobenthos is not affected by anomalous accumulations (LANG & REYMOND 1996a).

DEPTH-RELATED PATTERNS

Relative abundance of oligotrophic worm species (Fig. 1) and biomass of oligochaetes (Fig. 2) decreased significantly with depth. Sites were divided into two groups according to depth (Tab. 1): (1) 185 m - 240 m; (2) 245 m - 300 m. In group 1, the relative abundance of oligotrophic species and the biomass of oligochaetes were, in most cases, higher than 32%, and 14.7 g m⁻² respectively, the values predicted from total phosphorus concentrations in the water (see Stations and methods); the inverse was true for group 2.

In group 1, oxygen concentrations were, in most cases, higher than 4 mg l⁻¹; in group 2 they were lower than this value (Figs 1, 2). The presence of oligotrophic species was significantly associated with oxygen concentrations in excess of 4 mg l⁻¹ (test of Chi², P = 0.0004).

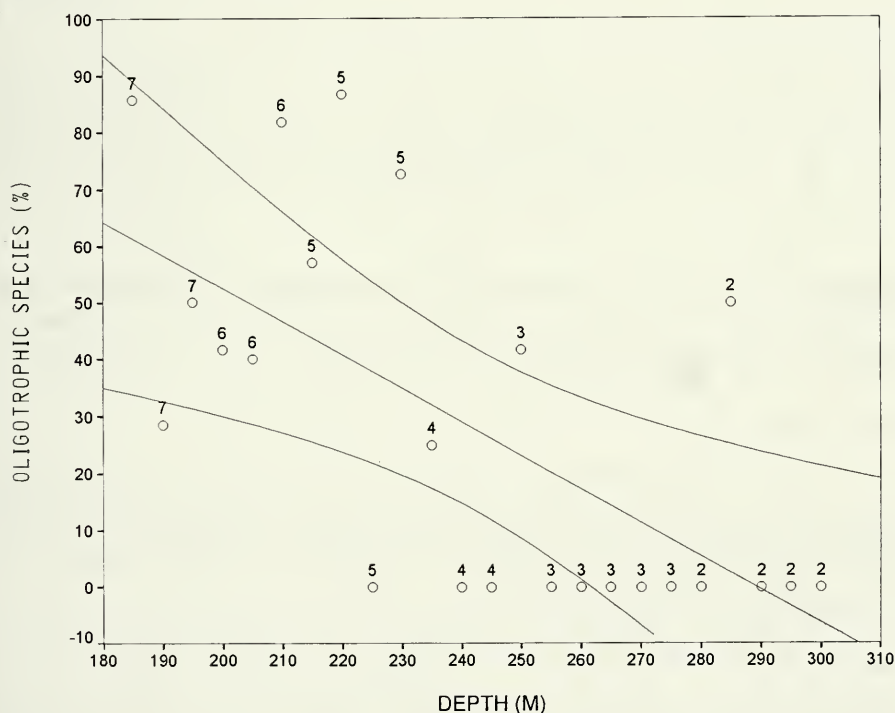


FIG. 1

Relative abundance (%) of oligotrophic worm species (Tab. 1) plotted against depth (m) of sampling sites. The linear regression line with the 99% confidence interval indicated on the figure. Oxygen concentrations (mg l⁻¹ rounded to the nearest integer) indicated above each point.

$$\text{Species (\%)} = -0.588 \text{ Depth} + 170.2$$

$$r^2 = 42.4\%$$

$$P = 0.001$$

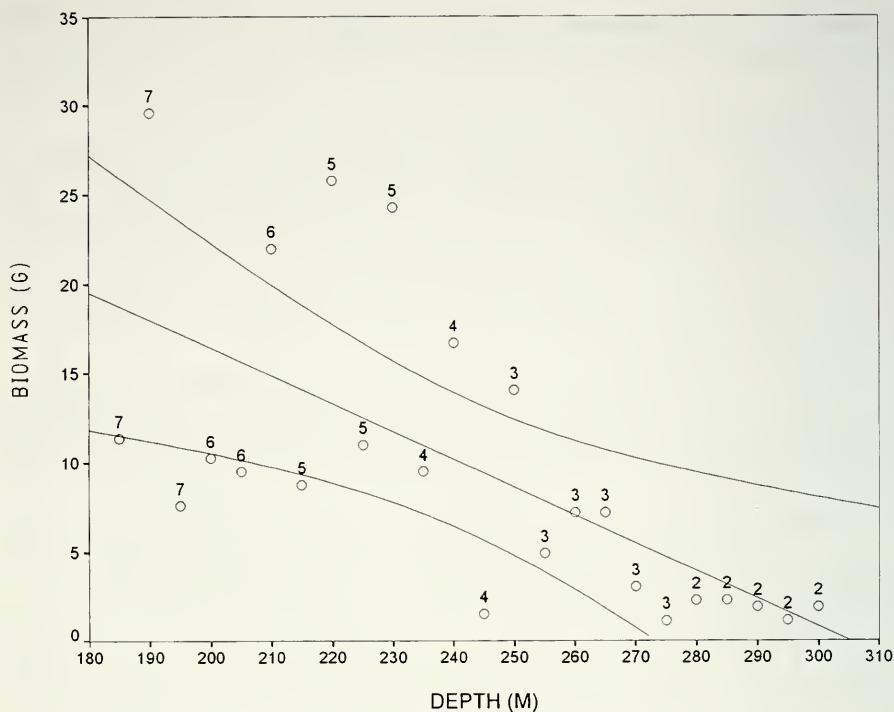


FIG. 2

Biomass (g m^{-2} wet weight) of oligochaetes plotted against depth (m) of sampling sites. Legend as in Fig. 1.

$$\text{Biomass (g)} = -0.156 \text{ Depth} + 47.55$$

$$r^2 = 43.1\%$$

$$P = 0.001$$

DISCUSSION

Mean relative abundance of oligotrophic species computed for the whole survey (Tab. 1, 185 m - 300 m) was close to 32%, the value predicted from total phosphorus concentrations (see Stations and methods). In contrast, the mean value computed for group 1 (185 m - 240 m) was higher than the predicted one; the inverse was true for group 2 (245 m - 300 m).

According to phosphorus concentrations in the water, Lake Geneva was mesotrophic in 1996. Mean relative abundance of oligotrophic species (Tab. 1) indicated that the lake was either mesotrophic (185 m - 300 m), oligo-mesotrophic (185 m - 240 m), or meso-eutrophic (245 m - 300 m). In the deepest area, the recovery was delayed by the persistence of low oxygen concentrations (Figs 1, 2).

In 1996, the oligotrophic worm species (Fig. 1) were not found deeper than 285 m (*Stylodrilus heringianus*) or deeper than 250 m (*Spirosperma velutinus*). In contrast, these species were present in the deepest area (300 m - 309 m) of Lake Geneva from 1958 to 1966 (JUGET 1967). Their mean relative abundance, computed

for 7 surveys, was around 27%; the maximum value (59%) being observed in 1963 after a cold winter.

Oligotrophic species were absent from the deepest area in 1976, 1978, and 1983 (LANG 1985). Their disappearance was attributed to the decrease of oxygen concentrations: from 1960 to 1967, minimal concentrations were always above 4 mg l⁻¹; from 1968 to 1983, they were below 3 mg l⁻¹ in 12 out of 16 years.

In 1996, mean relative abundance of oligotrophic species was relatively high between the depths of 185 m and 240 m (Tab. 1). However, *Stylodrilus heringianus* was the most abundant oligotrophic species, *Spirosperma velutinus* was relatively scarce (7.9% of the individuals) and *Bythonomus lemni* was very scarce.

Around 1900 (PIGUET & BRETSCHER 1913), the inverse situation prevailed in the oligotrophic Lake Geneva: *Spirosperma velutinus* and *Bythonomus lemni* were more abundant than *Stylodrilus heringianus*. Hence these species, which are less able to tolerate pollutants and low oxygen concentrations than *Stylodrilus heringianus* (LANG & LANG-DOBLER 1979), are the most reliable indicators of truly oligotrophic conditions for Lake Geneva.

During the first stage of recovery, the more tolerant *Stylodrilus heringianus* was clearly favored in the deep sediments (Tab. 1). Afterwards its gradual replacement by *Spirosperma velutinus* and *Bythonomus lemni* will indicate, more clearly than a mere increase of the abundance of oligotrophic species, the complete restoration of deep sediments. The beginning of such a change was already recorded in 1991, but at a depth of 40 m only (LANG & REYMOND 1992).

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